
# Nuclear Energy

Bernard.Frois@cea.fr

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International Herald Tribune
THE GLOBAL EDITION OF THE NEW YORK TIMES
GLOBAL.NYTIMES.COM

13 May 2013

# Readings of carbon dioxide pass a milestone

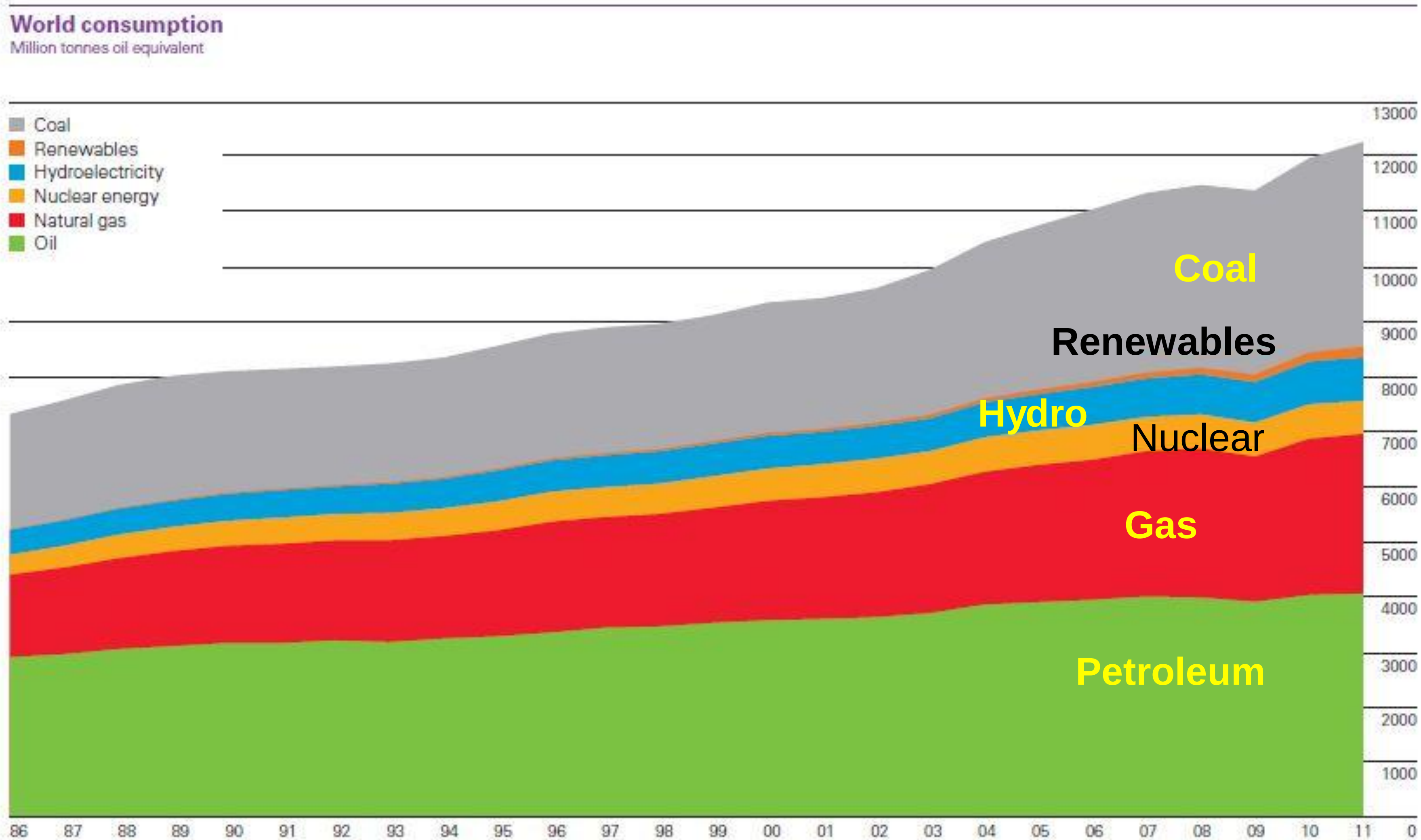
## Heat-trapping gas hits a level not seen in millions of years

For the entire period of human civilization, roughly 8,000 years, the carbon dioxide level was relatively stable near that upper bound. But the burning of fossil fuels has caused a 41 percent increase in the heat-trapping gas since the Industrial Revolution, a mere geological instant, and scientists say the climate is beginning to react, though they expect far larger changes in the future.

Indirect measurements suggest that the last time the carbon dioxide level was this high was at least three million years ago, during an epoch called the Pliocene. Geological research shows that the climate then was far warmer than today, the world's ice caps were smaller, and the sea level might have been as much as 60 or 80 feet, or 18 to 24 meters, higher.

Experts fear that humanity may be precipitating a return to such conditions — except this time, billions of people are in harm's way. ''It takes a long time to melt ice, but we're doing it,'' Dr. Keeling said. ''It's scary.''

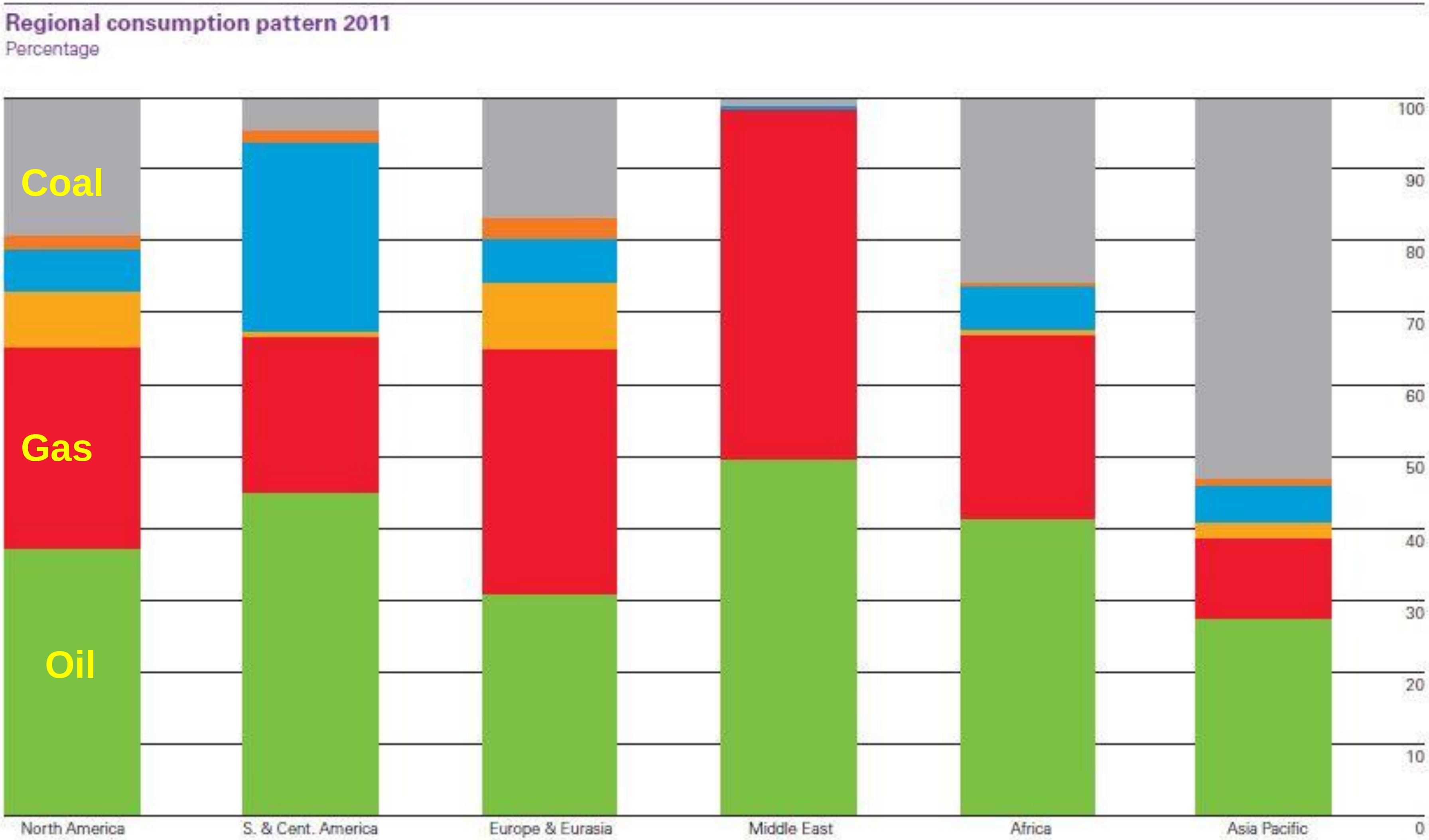
# World Consumption  MTOE




World primary energy consumption grew by 2.5% in 2011, less than half the growth rate experienced in 2010 but close to the historical average. Growth decelerated for all regions and for all fuels. Oil remains the world's leading fuel, accounting for 33.1% of global energy consumption, but this figure is the lowest share on record. Coal's market share of 30.3% was the highest since 1969.

BP report 2012

# Regional Consumption pattern 2011

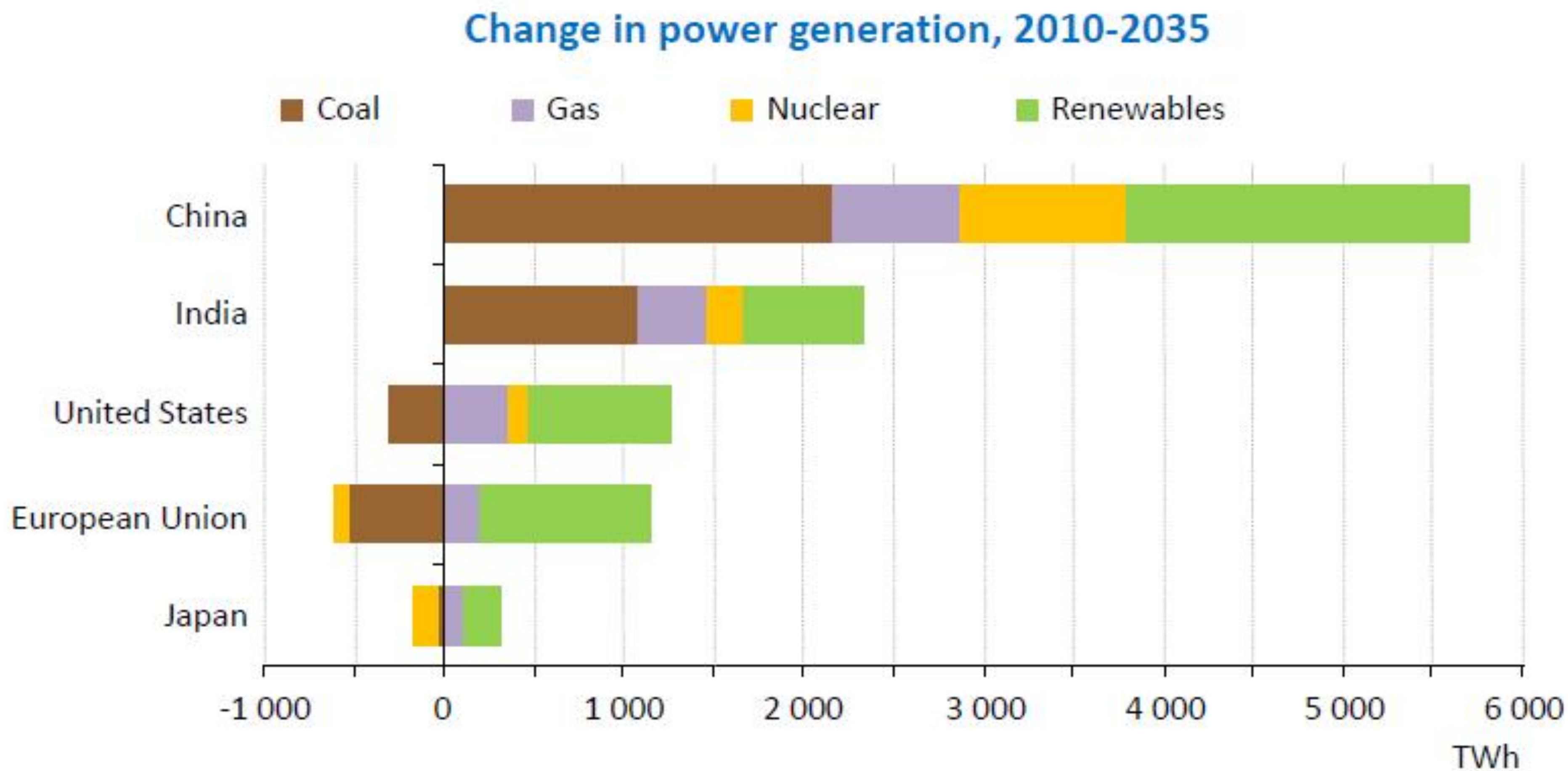



The Asia Pacific region is the world's largest energy consumer, accounting for 39.1% of global energy consumption and 68.6% of global coal consumption; the region also leads in oil consumption and hydroelectric generation. Europe & Eurasia is the leading region for consumption of natural gas, nuclear power, and renewables. Coal is the dominant fuel in the Asia Pacific region; natural gas is dominant in Europe & Eurasia, and oil is dominant in all other regions.

BP report 2012

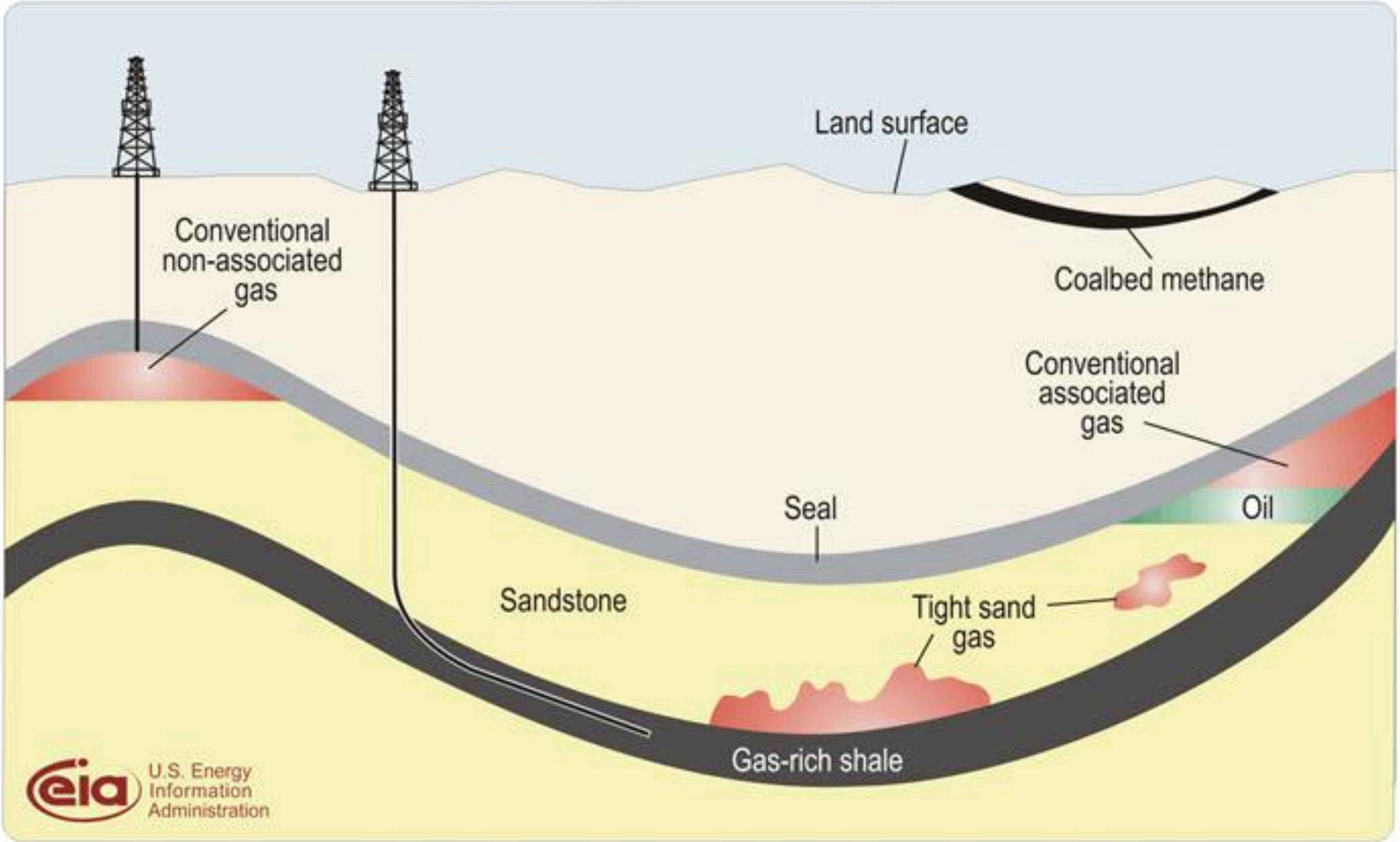
# A power shift to emerging economies

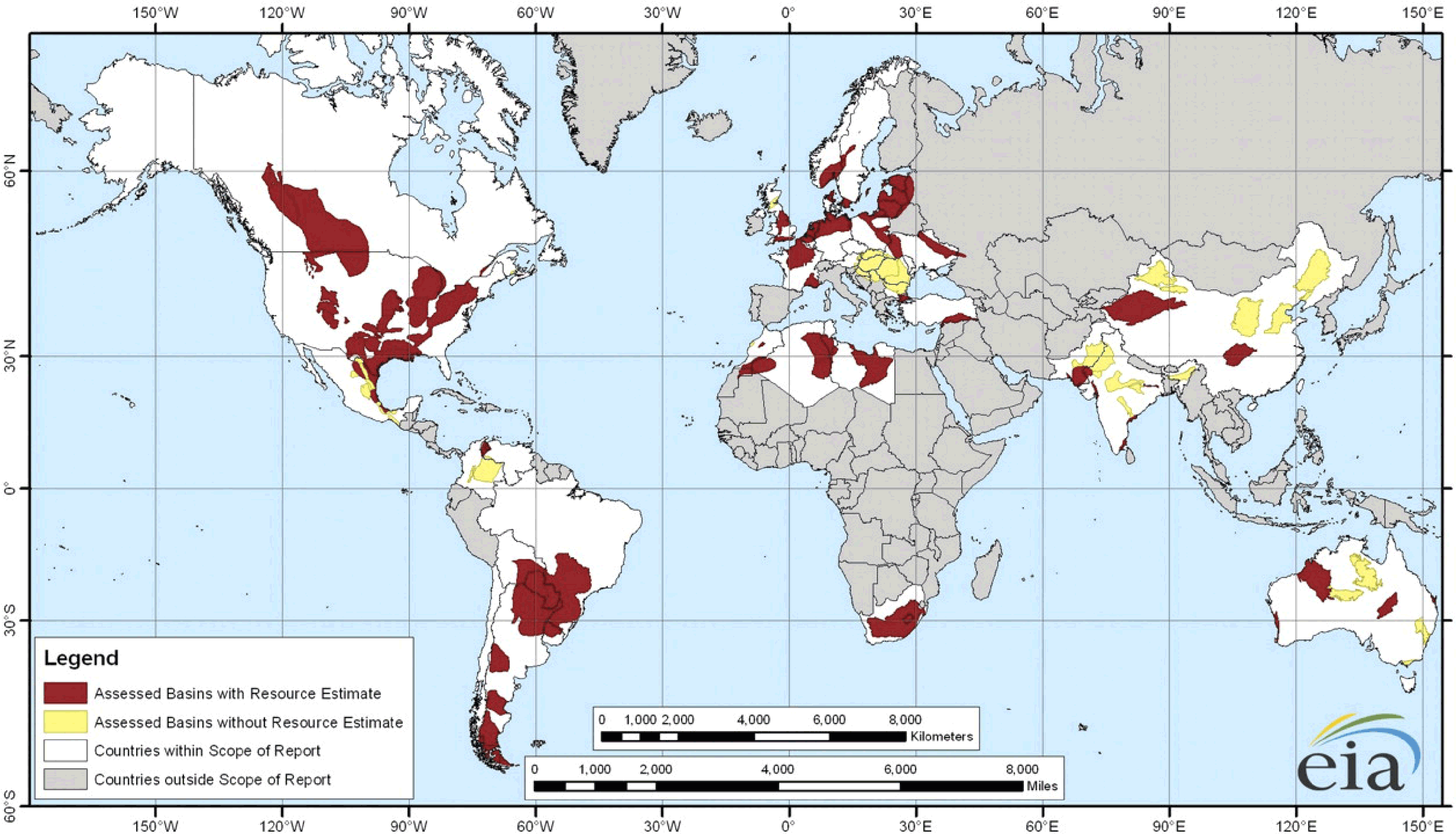
WORLD ENERGY OUTLOOK 2012




***The need for electricity in emerging economies drives a 70% increase in worldwide demand, with renewables accounting for half of new global capacity***

## Schematic geology of natural gas resources




150°W
120°W
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60°W
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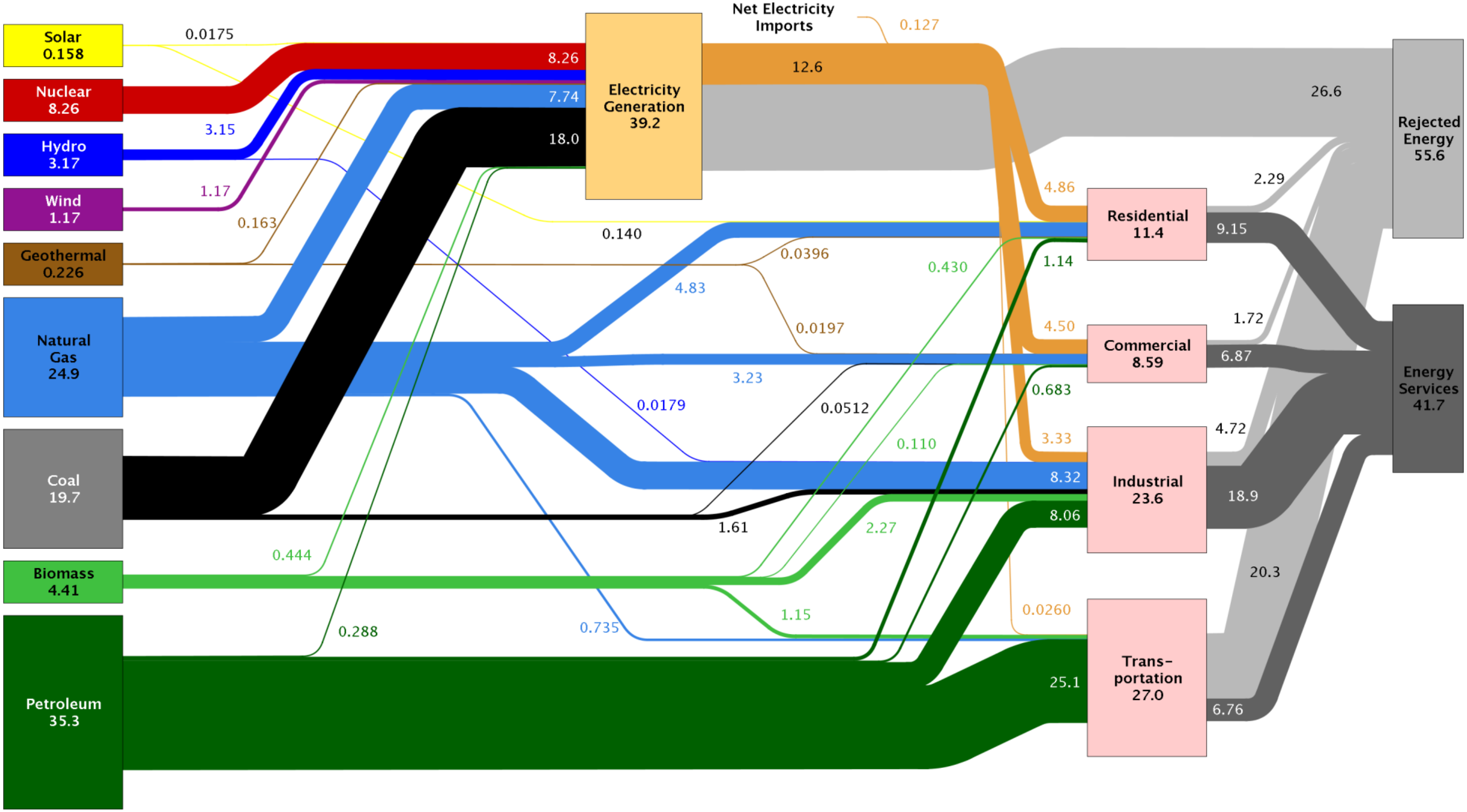
0°
30°E
60°E
90°E
120°E
150°E
60°N
30°N
0°
30°S
60°S
Legend
Assessed Basins with Resource Estimate
Assessed Basins without Resource Estimate
Countries within Scope of Report
Countries outside Scope of Report
0 1,000 2,000 4,000 6,000 8,000
Kilometers
0 1,000 2,000 4,000 6,000 8,000
Miles
eia

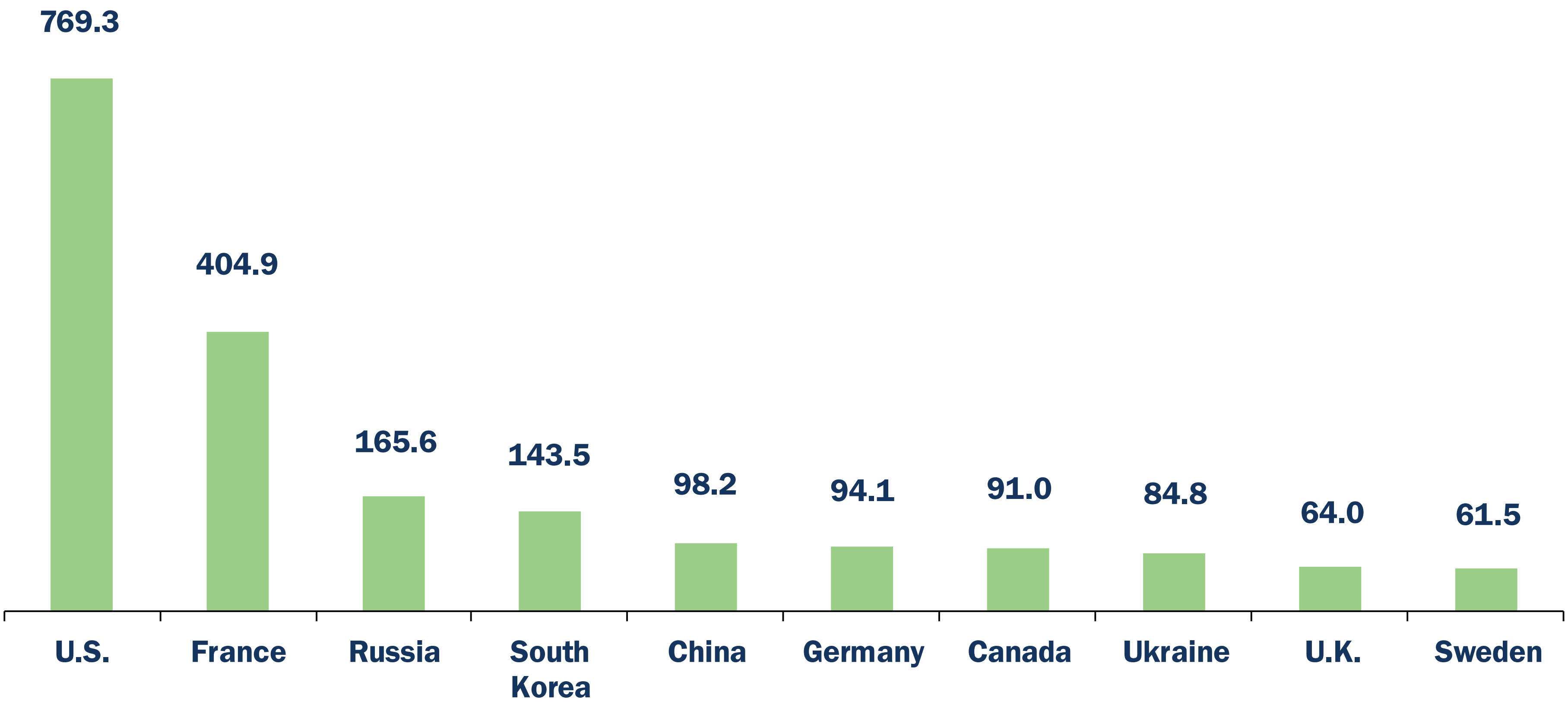
# Estimated U.S. Energy Use in 2011: ~97.3 Quads

Lawrence Livermore National Laboratory




Source: LLNL 2012. Data is based on DOE/EIA-0384(2011), October, 2012. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

# Top 10 Nuclear Generating Countries
## 2012, Billion kWh




Source: International Atomic Energy Agency
Updated: 5/13

BLUE RIBBON COMMISSION ON AMERICA'S NUCLEAR FUTURE

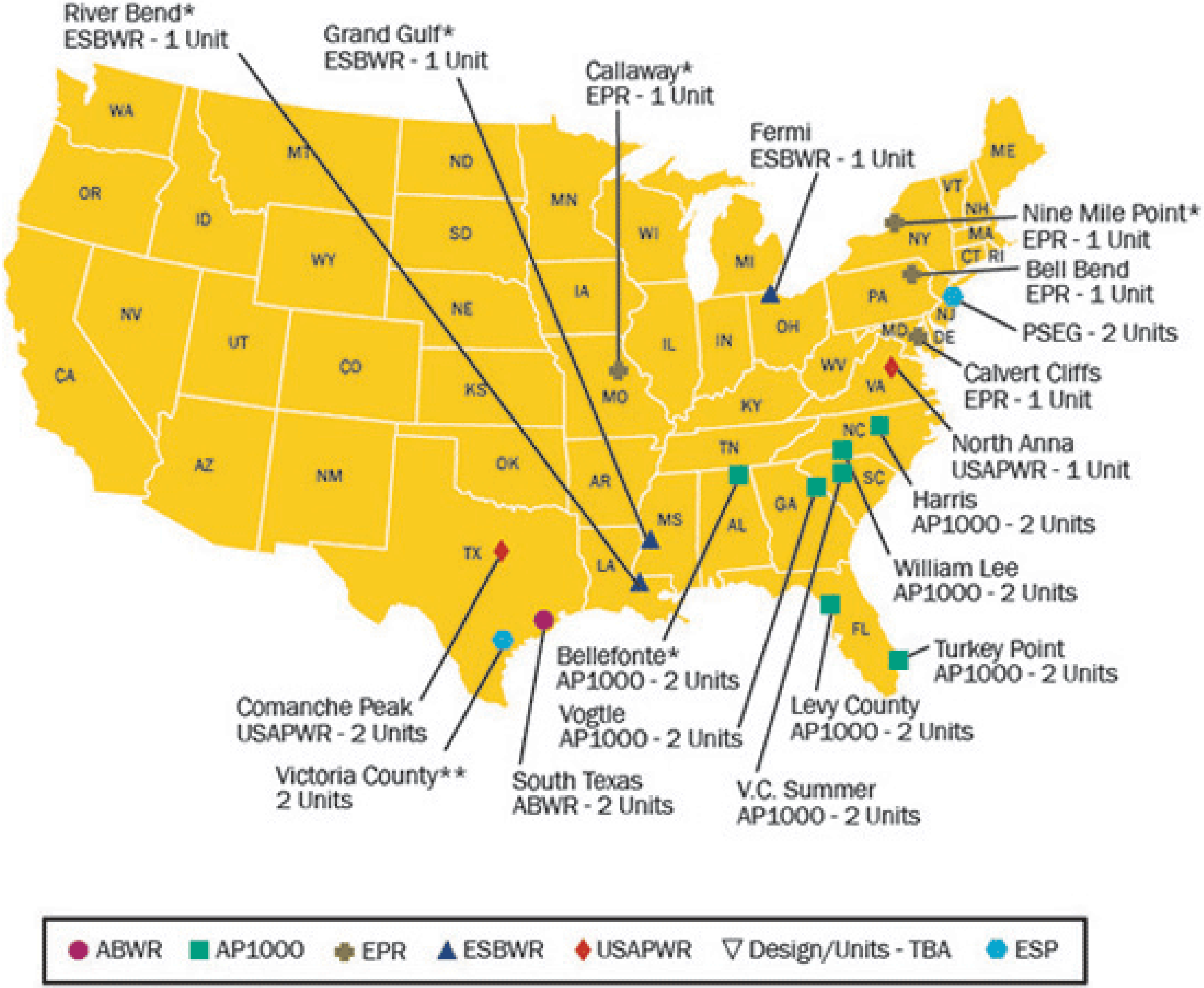





# Report to the Secretary of Energy

JANUARY 2012

# NPP produce 20% of electricity in the USA




*Review Suspended by Applicant

** COL Application Amended by Applicant to ESP on 03/25/2010

# Nuclear Energy costs

**Electricity Production Cost in the USA by Fuel Type (2012)**

- Nuclear: 2.40 cents per kWh
- Coal: 3.27 cents per kWh
- Natural gas: 3.40 cents per kWh
- Oil: 22.48 cents per kilowatt-hour (kWh)

Nuclear energy is cost competitive with other forms of electricity generation, except where there is direct access to low-cost fossil fuels.

Fuel costs for nuclear plants are a minor proportion of total generating costs, though capital costs are greater than those for coal-fired plants and much greater than those for gas-fired plants.

In assessing the economics of nuclear energy, decommissioning and waste disposal costs are fully taken into account.

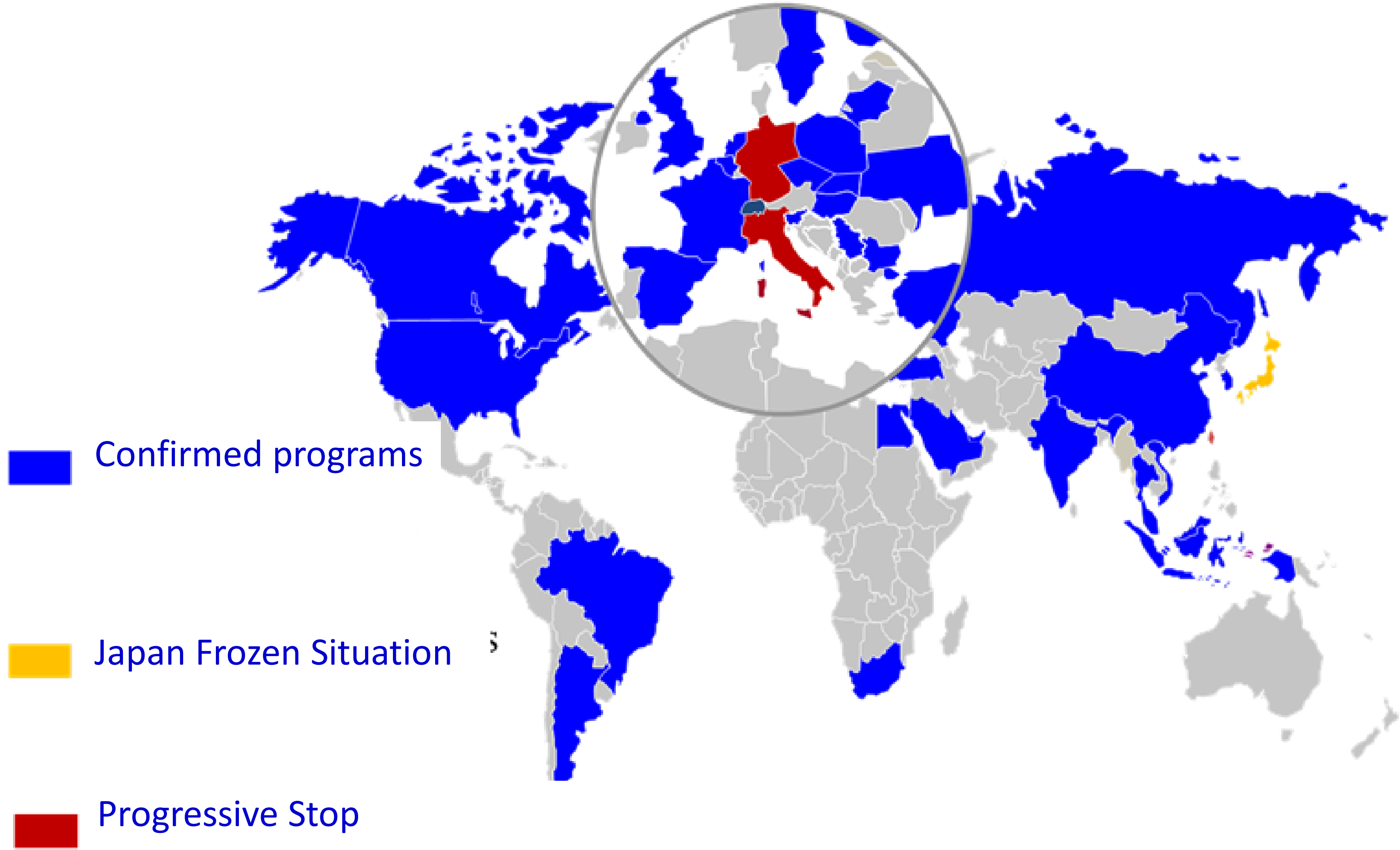
Nuclear Energy is a powerful  long term investment.

# Price of electricity in US cents/kW/h

| Technology | Country | At 5% discount rate |
|---|---|---|
| Nuclear | OECD Europe | 5.0-8.2 |
| | **China** | **3.0-3.6** |
| Black coal with CCS | OECD Europe | 8.5 |
| Brown coal with CCS | OECD Europe | 6.8-8.3 |
| CCGT with CCS | OECD Europe | 9,8 |
| Large hydro-electric | OECD Europe | 7,4-23,1 |
| | **China 3 Gorges** | **2,9** |
| | **China other** | **1,2-1,7** |
| Onshore wind | OECD Europe | 9,0-14,6 |
| | **China** | **5,1-8,9** |
| Offshore wind | OECD Europe | 13,6-18,8 |
| Solar photovoltaic | OECD Europe | 28,7-41 |
| | **China** | **12,3-18,6** |

Source: OECD/IEA-NEA, 2010, Projected Costs of Generating Electricity, Tables 3.7
This shows the levelised cost, which is the average cost of producing electricity including capital, finance, owner's costs on site, fuel and operation over a plant's lifetime.

# World Nuclear Power Situation 2012




As of 18 January 2013, in 31 countries 437 nuclear power plant units with an installed electric net capacity of about 372 GW are in operation

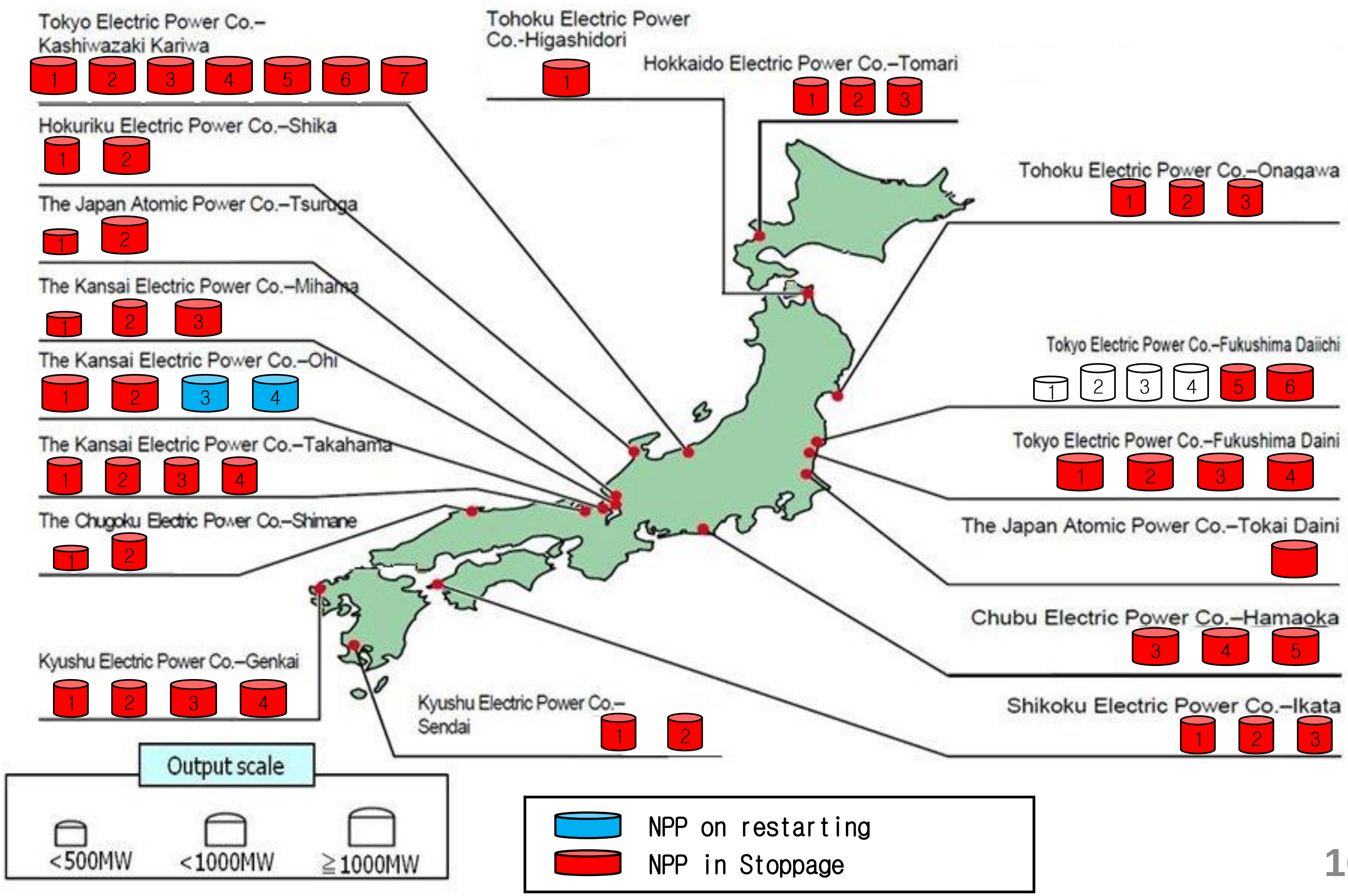
# Nuclear energy capacity is worldwide increasing steadily

- Most reactors on order or planned are in the Asian region, though there are major plans for new units in the USA and Russia.
- Significant further capacity is being created by plant upgrading.
- Plant life extension programs are maintaining capacity (40 years to 60 years)
- 437 nuclear power reactors operate in 31 countries plus Taiwan, with a combined capacity of over 372 GWe. In 2011 these provided about 13.5% of the world's electricity.
- 68 power reactors are currently being constructed in 15 countries plus Taiwan with an installed capacity of 65 GW, notably China, India, Russia and South Korea.
- The International Atomic Energy Agency's most realistic estimate is that 90 new nuclear plants will enter service by 2030 in India. Ten new nuclear plants went online over the past two years. India now envisages increasing the contribution of nuclear energy to overall electricity generation capacity from 3.2% to 9% within 25 years. By 2020, India's installed nuclear energy generation capacity will increase to 20,000 MW.
- China has 26 various new reactors in construction (29 GW) including 2 EPR

# Nuclear Power Plants in Japan



There are 54 units of nuclear power plants in Japan. (The decision to decommission Units 1 – 4 at the TEPCO Fukushima Daiichi Nuclear Power Station has been made.) 48 units (in red) are in stoppage, and 2 units of them (in blue) are now on restarting.



# Lessons From Fukushima

## International response

- ✓*Sharing information to have the public understand*
- ✓*Checking & Stress tests*
- ✓ *Adapt/Upgrade NPPs in operation & construction*

## Learnings

- ✓ *Very unlikelly events may happen*
- ✓*Enhance emergency preparedness*
- ✓*Revisit « beyond design basis accidents »*

## Safety: towards more internationalization

- ✓ *Harmonizing safety requirements + Assessing relevance to Gen-3 reactors*
- ✓ *Enhancing cooperation on regulatory research on Safety & Radiation protection*
- ✓ *Progress of multinational evaluation towards international licensing convergence*

# Main Actions proposed by French utility EDF after the post Fukushima CSA (stress tests)

**Earthquake, Flood and other hazards**

*Improve protection of safety functions*

**LUHS / SBO Reactor, SFP**

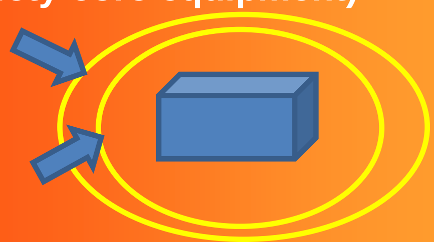
*Avoid core melt and fuel uncovery*

**Severe accident management**

*Limit the releases*

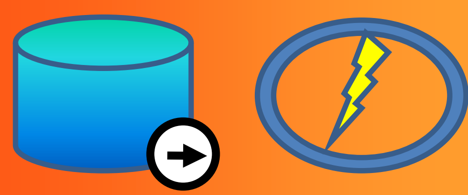
*Multi-units crisis management of extreme events*

**Reinforcement of protections against extreme hazards (safety functions, hardened safety core equipment)**



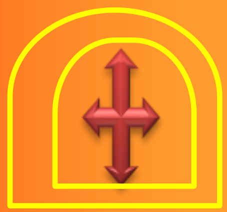
**Additional air & electricity supply**

**Additional water reserves & supply**



**Protective measures in case of core meltdown**

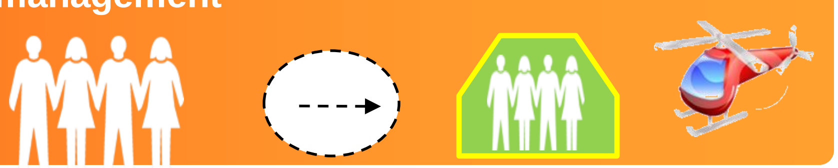
**Studies / knowledge of phenomena**



**Reinforcement of the crisis organisation & management**

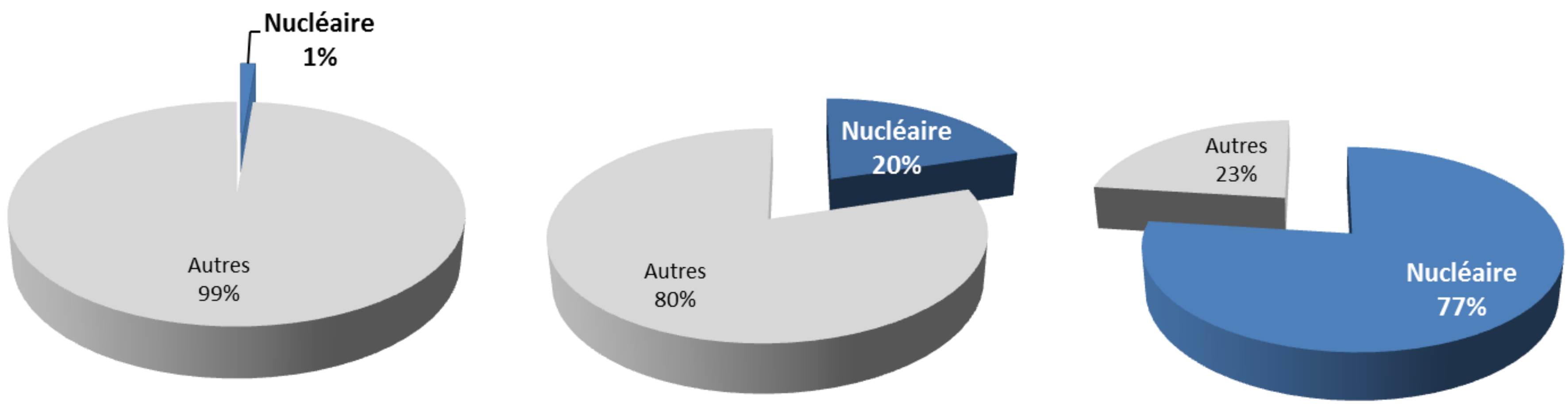
**Resources, installed & mobile Equipment**

**Emergency Crisis Centre + FARN**



# Nuclear reactors in construction

# Nuclear electricity production




**China** **United States** **France**

| | China | USA | France |
|---|---|---|---|
| **In operation** | 12,54 GW | 100,5 GW | 63,26 GW |
| **In construction** | 29,14 GW | 1,1 GW | 1,7 GW |
| **Horizon 2020** | 70 / 80 GW | - | - |

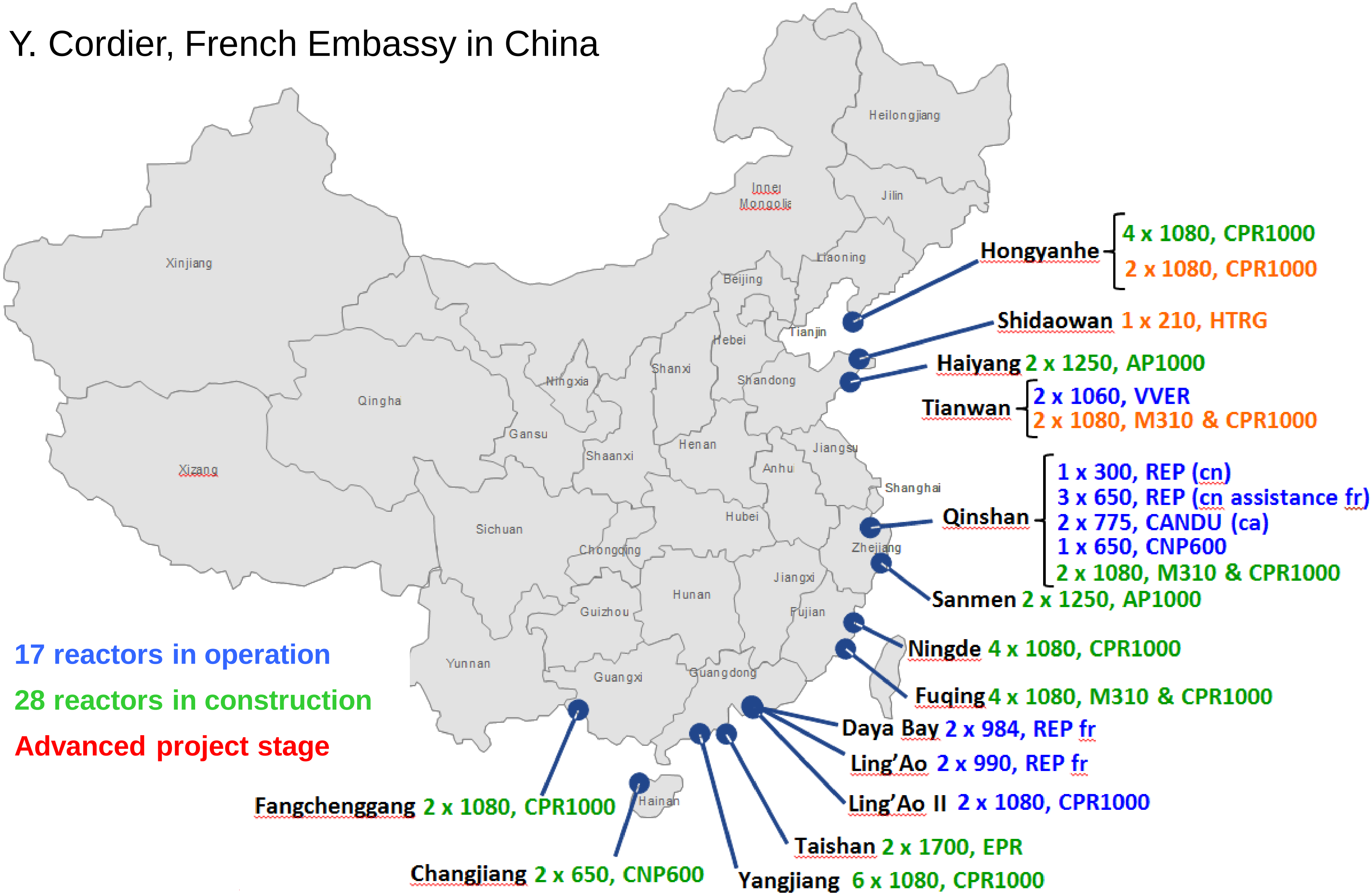
*Sources : (1) CIA, The world factbook; (2) World Nuclear Association*

- Nuclear Energy produces only 1,3% of China Electricity 1055 GW)

P. Y. Cordier, French Embassy in China

# NPP in China: 30 Gw 1% electricity share

P. Y. Cordier, French Embassy in China



# Taishan EPR – First EPR in operation 2014

# Radioactive Waste Management

- Nuclear power is the only large-scale energy-producing technology which takes full responsibility for all its wastes and fully costs this into the product.
- The amount of radioactive wastes is very small relative to wastes produced by fossil fuel electricity generation.
- Used nuclear fuel may be treated as a resource or simply as a waste.
- Nuclear wastes are neither particularly hazardous nor hard to manage relative to other toxic industrial wastes.
- Safe methods for the final disposal of high-level radioactive waste are technically proven; the international consensus is that this should be geological disposal.

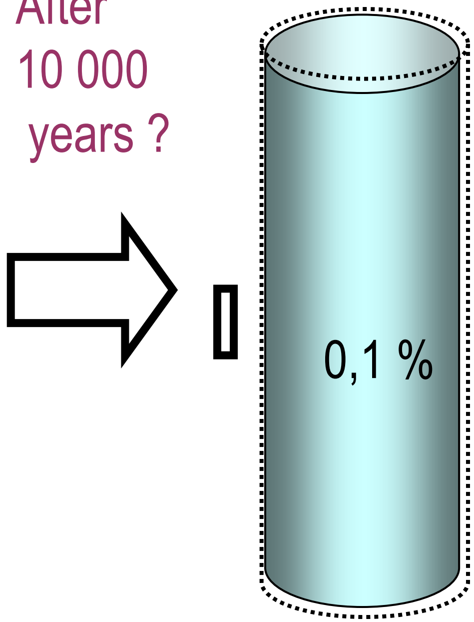
# Nuclear Wastes Management
# International consensus exists between experts

- The safest range of possible solutions are based on multi barrier confinement together with deep geological underground storage
- Long term storage in safe conditions is feasible but needs continuous surveillance and maintenance.
- Finland, France, and Sweden will be the first countries to store High Activity and Long Life radioactive isotopes

# Long term durability of vitrified waste, alteration by water

Vitrified waste

After
10 000
years ?




Understanding of the phenomena

$$\frac{\partial x}{\partial t} = v \quad x = \frac{C_{Boron}(t)}{\frac{S}{V}\rho X^{Solid}_{Boron}}$$

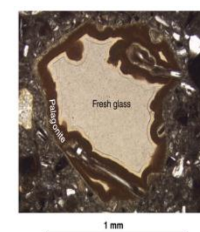
$$\frac{\partial C_{Si}(t)}{\partial t} = v C_{slb}\frac{S}{V} + F(C_0 - C_{Si}(t))$$

$$C_{slb} = C^{Glass}_{Silica}(1 - f(C_{Si}(t)))$$

$$v = v_0\left(\frac{1 - \frac{C_{Si}(t)}{C^*}}{1 + v_0\frac{C_{slb}x}{D_g C^*}}\right)$$

Construction of mathematical
Models and forecasts

Validation of calculations (natural analogues, expert opinions,…)



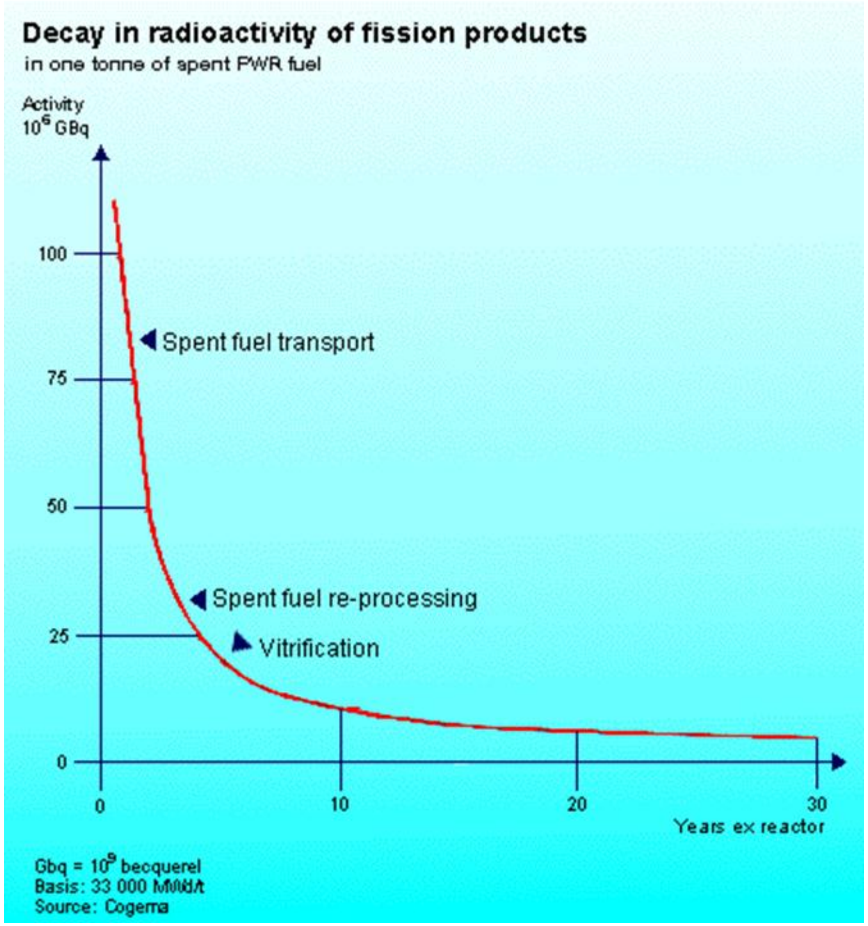

Fundamental research

# Radioactivity of Nuclear Wastes

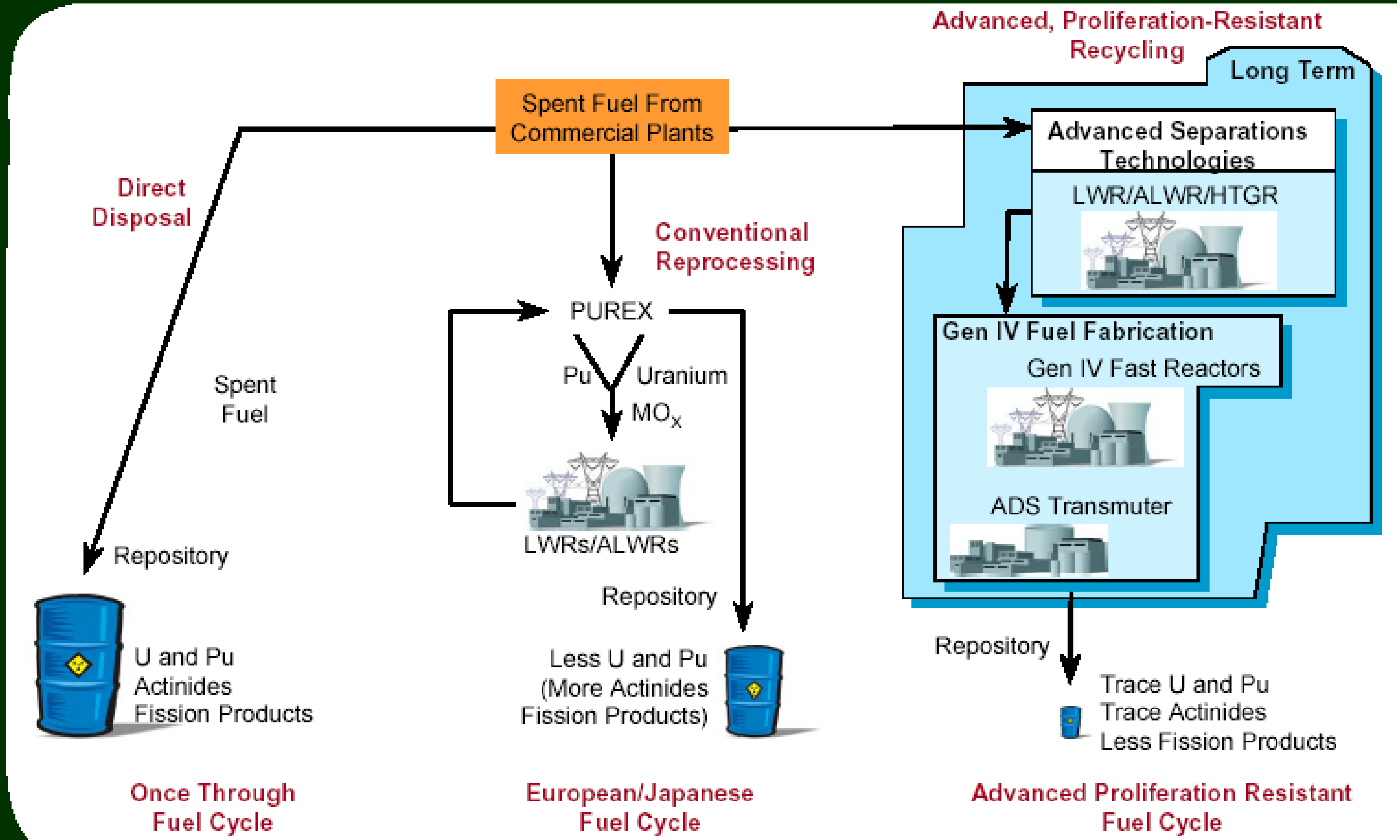
A 1000 MWe light water reactor will generate 200-350 $m^3$ low- and intermediate-level waste per year.

Discharge about 20 $m^3$ (27 tonnes) of used fuel per year, 75 $m^3$ disposal volume if it is treated as waste. Finland, Sweden,etc.

With reprocessing only 3 $m^3$ of vitrified waste (glass) is produced, equivalent to a 28 $m^3$ disposal volume following placement in a disposal canister. Solution adopted by Belgium,  France, China, Japan, Russia, Switzerland, UK etc.



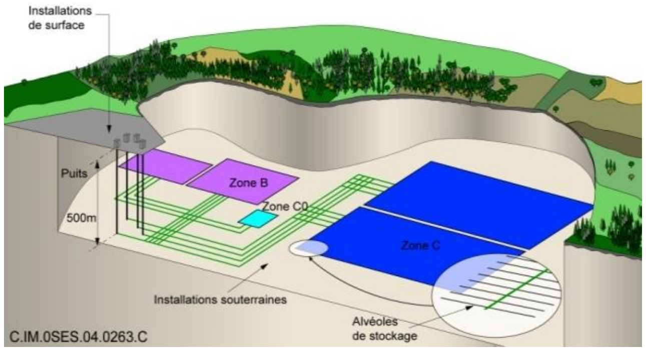
# Approaches to Spent Fuel Management:
*Long Term Technologies*





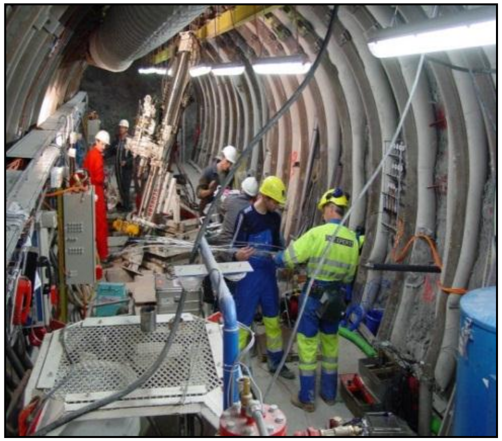

# Sustainable management of nuclear wastes
# French Law of June 28, 2006

- ✓ **France has a National Plan managed by** ANDRA Mastering radioactive waste
- ✓ **Stepwise program for Long-Lived Waste ; P&T , geological repository and interim storage**
- ✓ **Specifies the roadmap to have a retrievable geological repository in operation by 2025**




*Design project for HLL waste disposal,* ***in progress***

*Research from Underground laboratory (URL),* ***in operation***



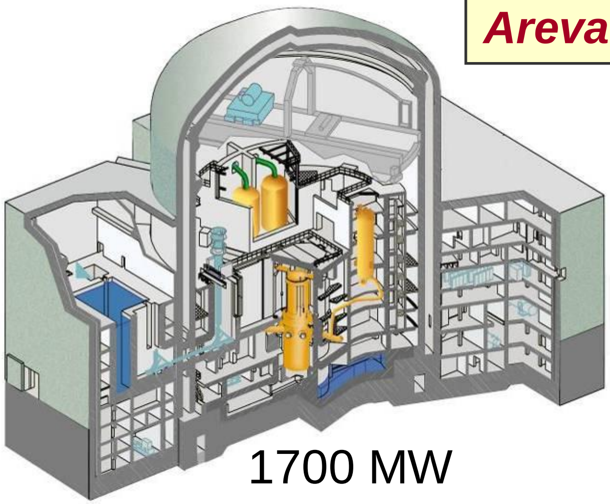
- ✓ **Secured long term funding**

# New types of nuclear reactors

- Advanced LWR’s: Increased safety generation III +. Several new designs.
- Generation IV fast reactors transmute long half-life wastes and then fissions them for power. New fuel cycles needed.

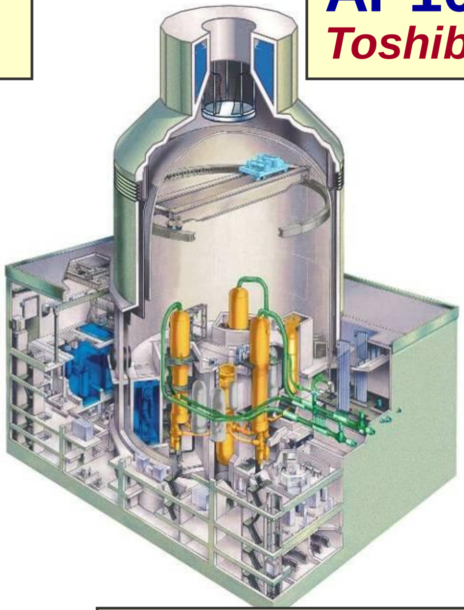
# ALWR's from the USA, Japan, Russia & Europe

**EPR**
*Areva NP*

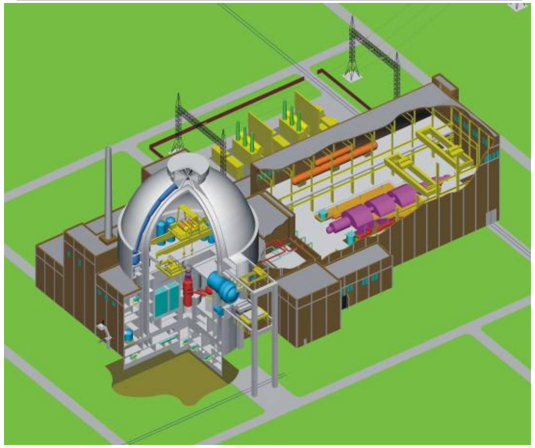


1700 MW

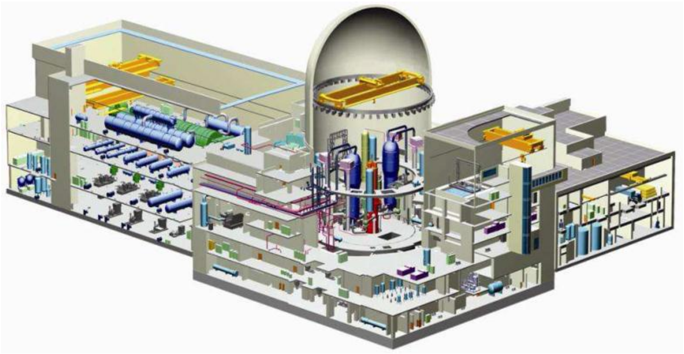
**AP1000**
*Toshiba-West.*



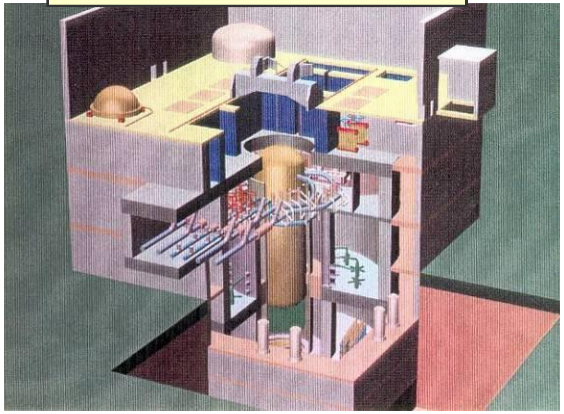
**АЭС-92**
**с ВВЭР—1000**
*АСЭ РОСАТОМ*



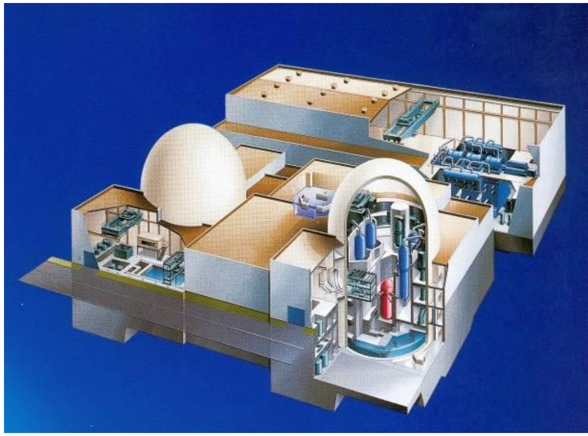
**APR-1400**
*KHNP*



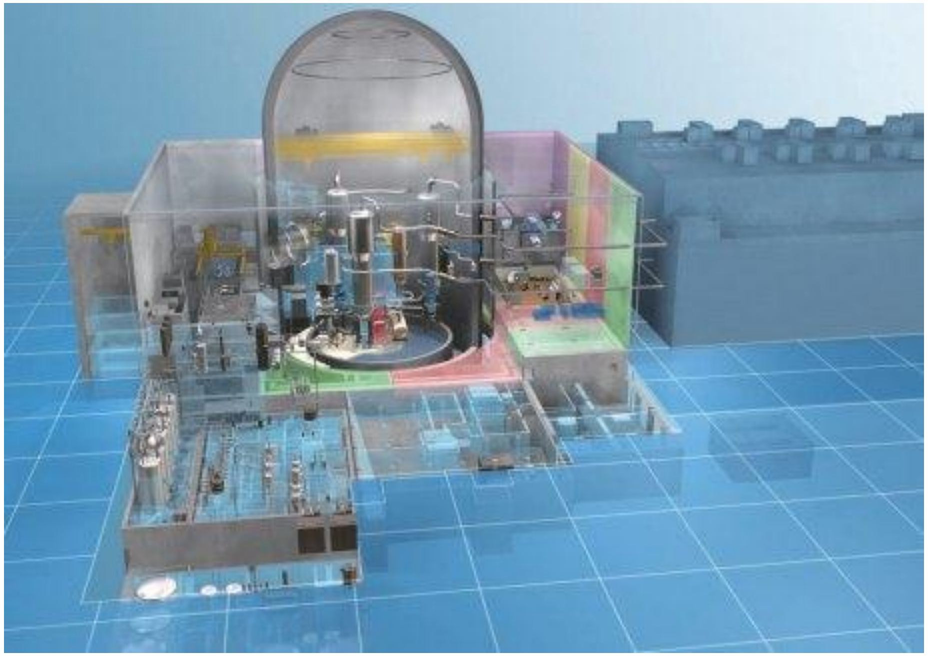
**ESBWR**
*GE & Hitachi*



**APWR**
*Misubishi*



# Turkey continues to invest in nuclear energy



The ATMEA company will supply Turkey with 4 mid-sized Generation III+ pressurized water reactor (PWR 1100 MW) using innovative, reliable, proven technology. The ATMEA company is a joint venture between AREVA and Mitsubishi Heavy Industries (MHI) Deployment expected in the early 2020s. Cost $22 billions (3 May 2013)

GDF Suez will be "providing its expertise as a nuclear power developer and operator

# Fast Reactors and Related Fuel Cycles: Safe Technologies and Sustainable Scenarios

700 experts from 34 countries and 3 international organizations gathered in Paris on 4–7 March 2013.

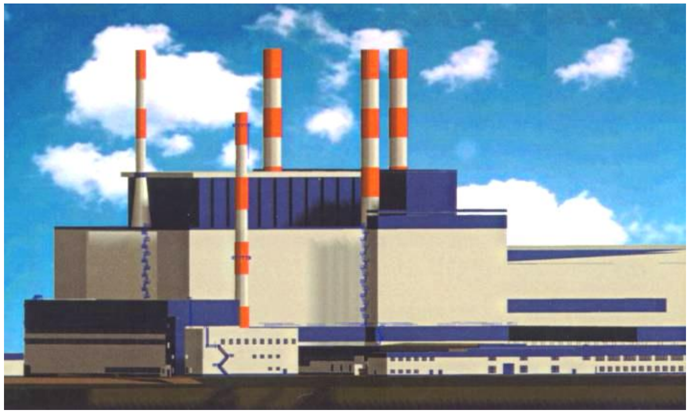
Fast reactor technology has the potential to ensure that energy resources, which would run out in a few hundred years using today's technology, will actually last several thousand years.

Fast reactors also reduce the volume and toxicity of the final waste.

With reprocessing Nuclear Energy becomes sustainable

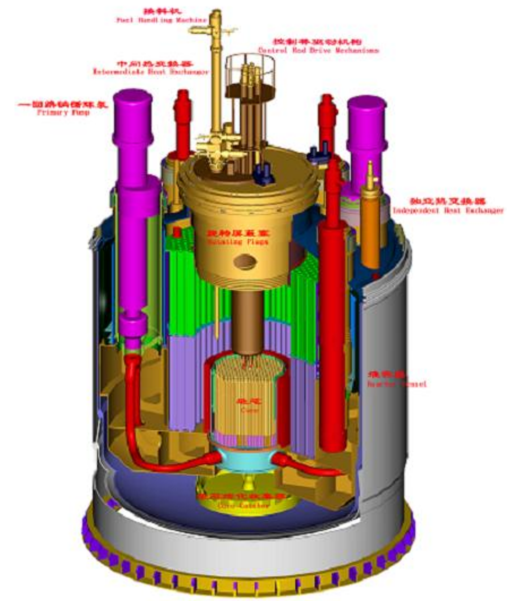
Several fast reactors are already in construction using sodium as coolant.

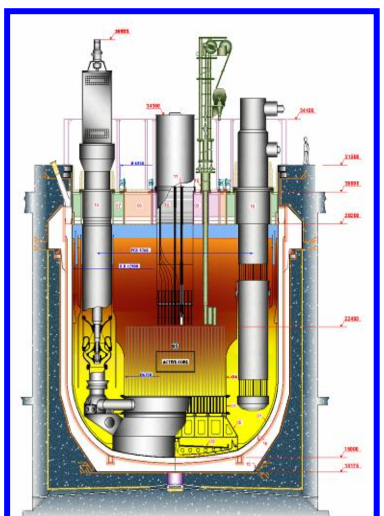
# Sodium Fast Reactors in India, Russia & China



**BN-800 (Russia)**

800 MWe, 2014





**PBFR (India)**

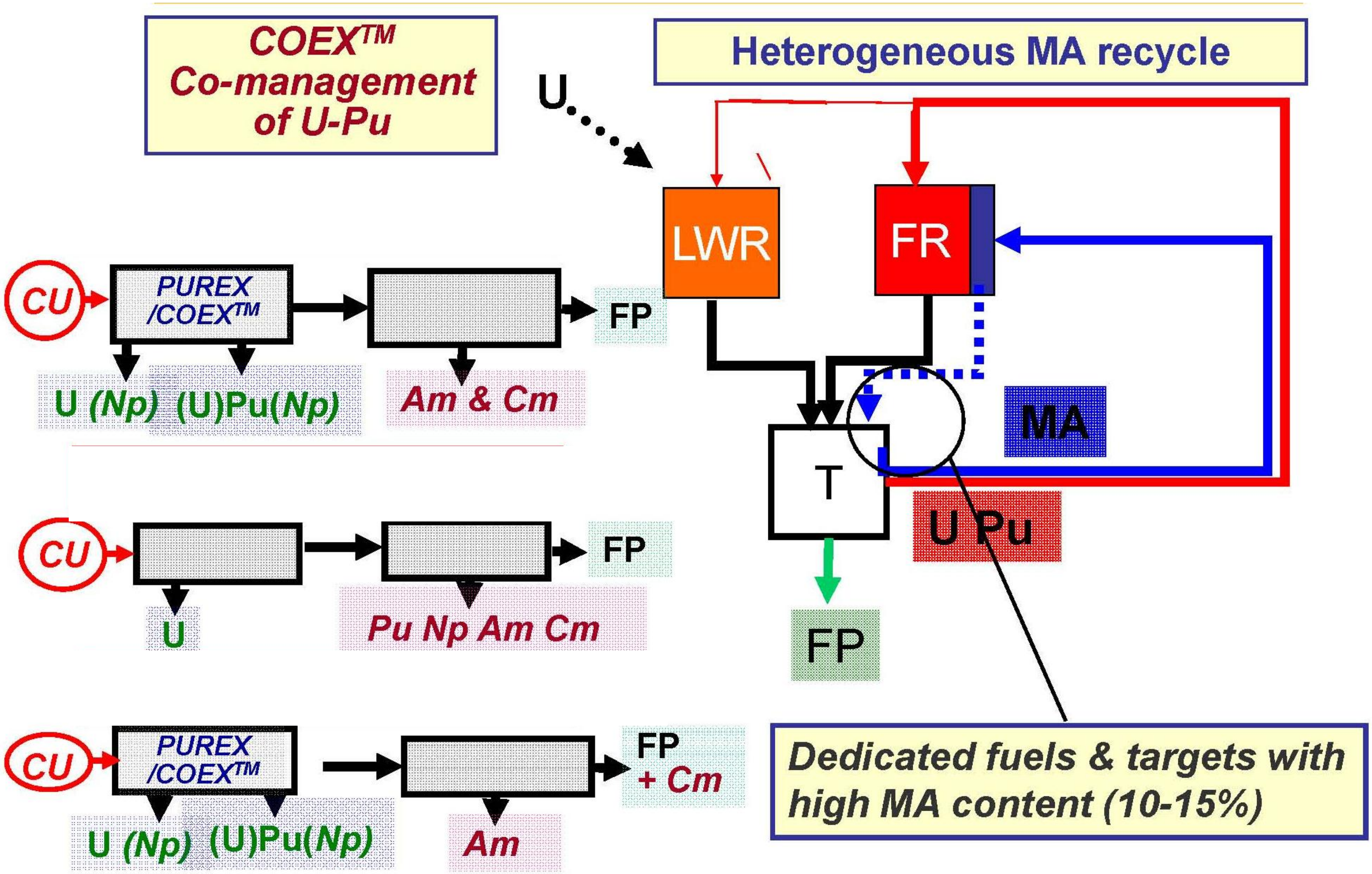
500 MWe, 2012

**CEFR (China)**

65 MWth, 20 MWe,

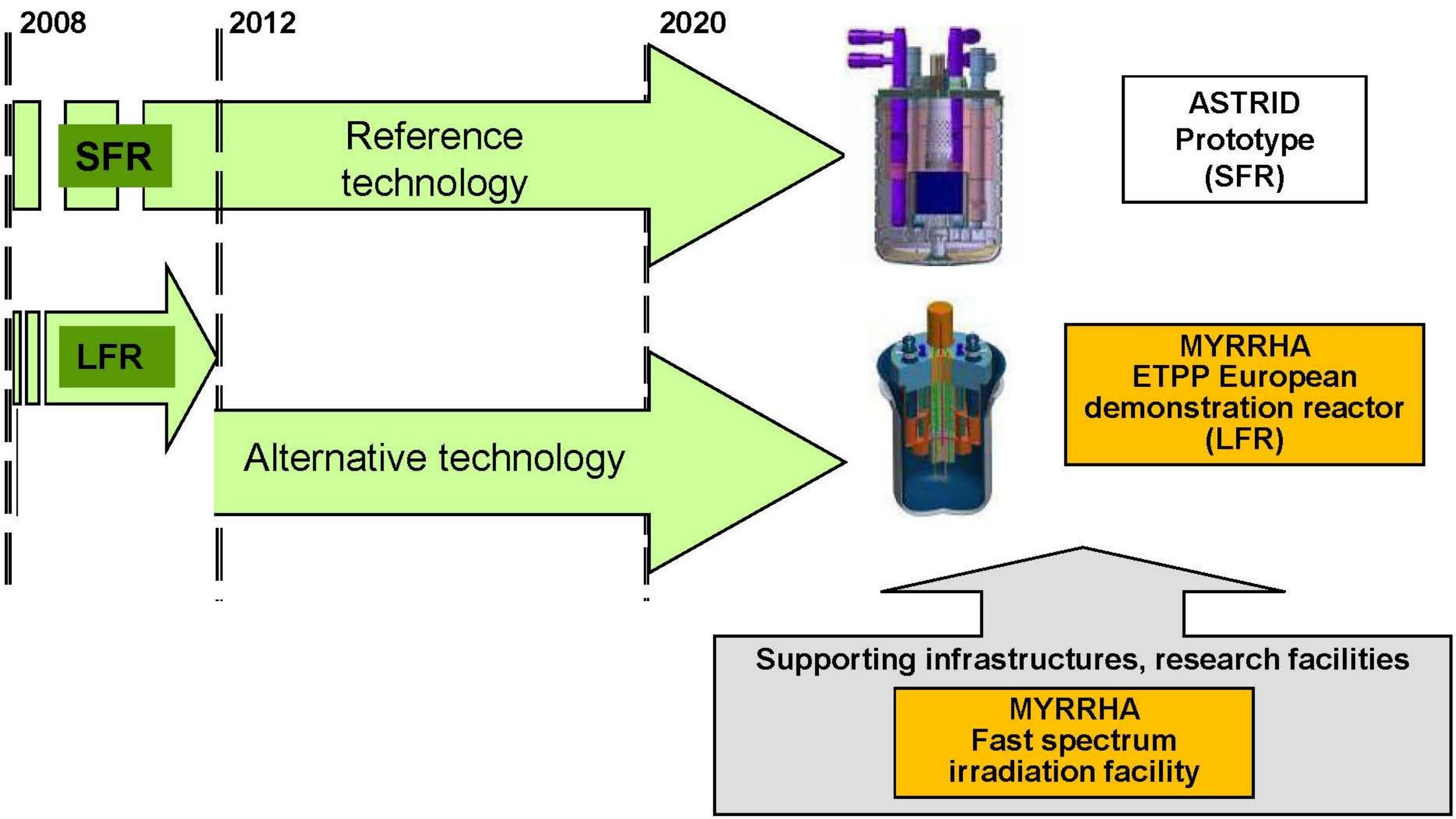
July 2010

# New Advanced Fuel Cycles

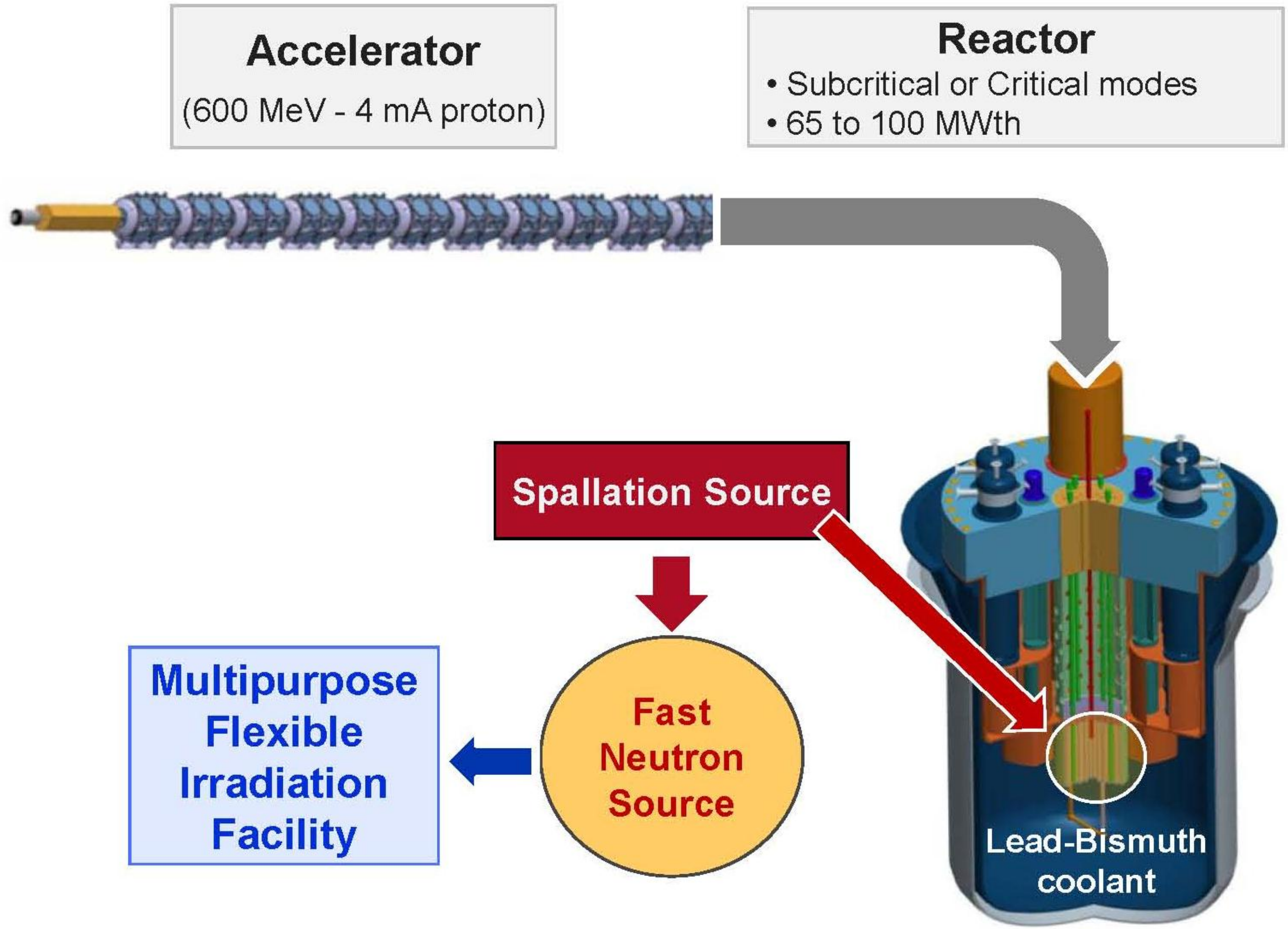


# MYRRHA part of ESNII

## European Sustainable Nuclear Industrial Initiative



# MYRRHA - Accelerator Driven System

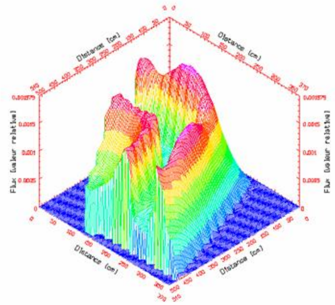


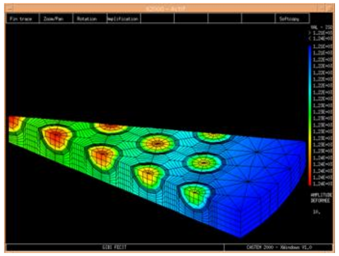
# Pure and Applied R&D has a crucial role

- Basic understanding: physics, chemistry, simulation…( separation, conditioning, irradiation, multi-scale models…)
- Materials science
- Nuclear Wastes management
- Accelerator Driven Systems
- Future reactors concepts
- Radiobiology and nuclear toxicology
- Expertise and validation of new concepts
- Information of the public

# R&D on future nuclear energy systems

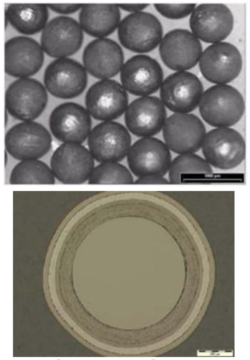
## Computational codes for design studies & operating analyzes



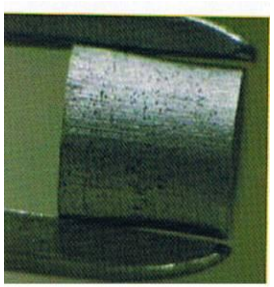


Computational tools

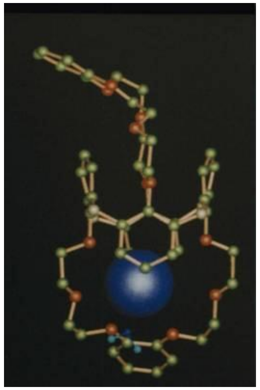
## Fuel & fuel cycle



Particle Triso

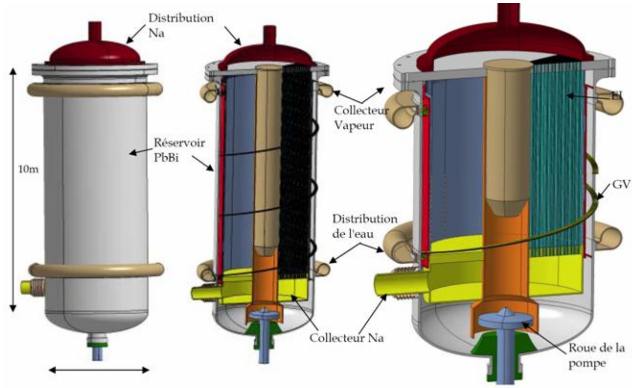


Combustible Act Min



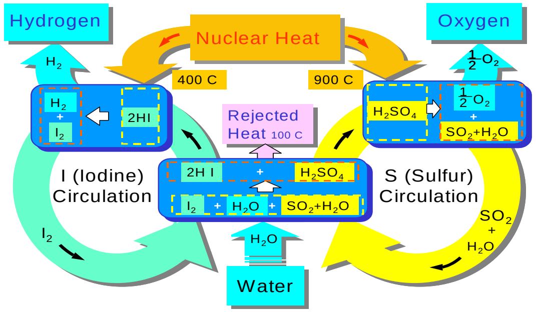
***Future nuclear systems' studies: multi-physics R&D interfaced with fundamental research, applied research, and engineering***

## Materials & Components



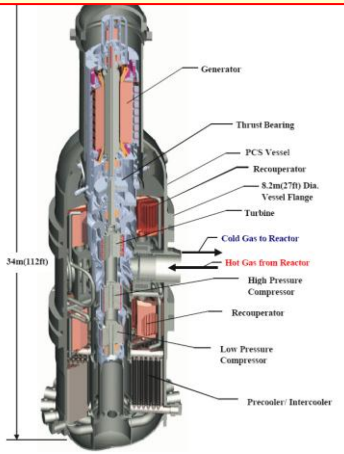

Sodium exchanger / Conversion system

## Hydrogen production



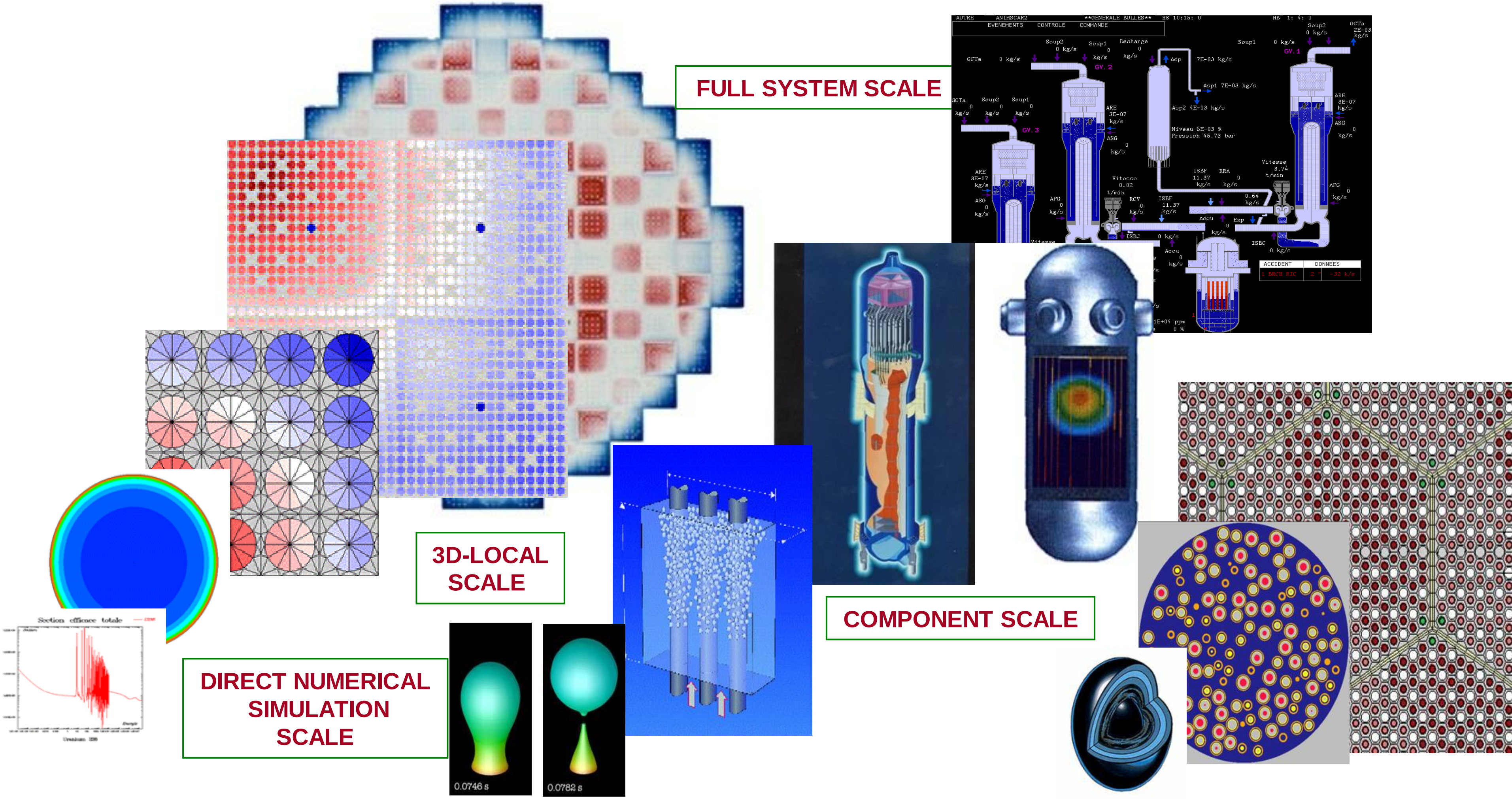

I/S Process

## Power conversion

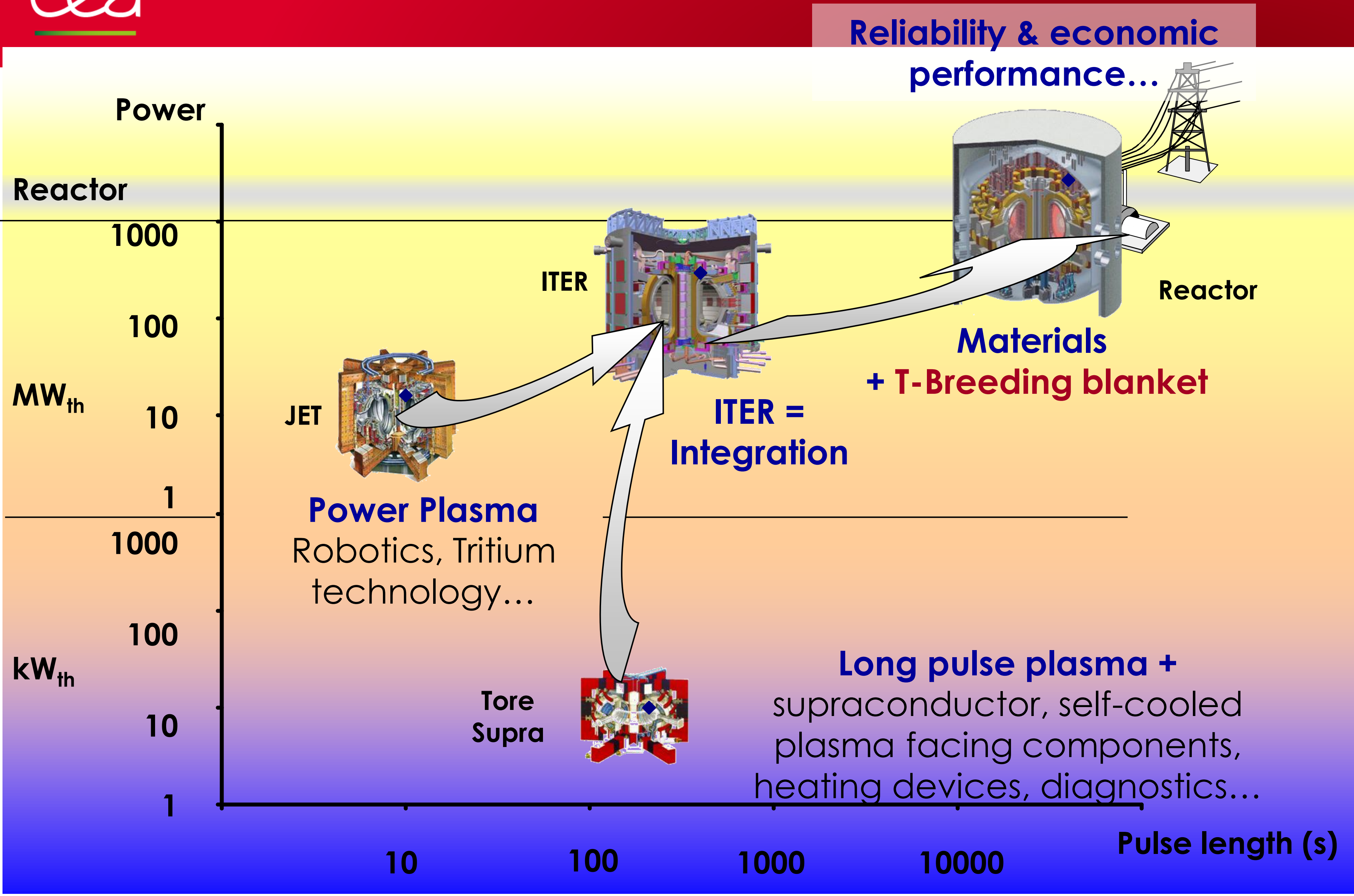


# Computational Tools for Nuclear Systems

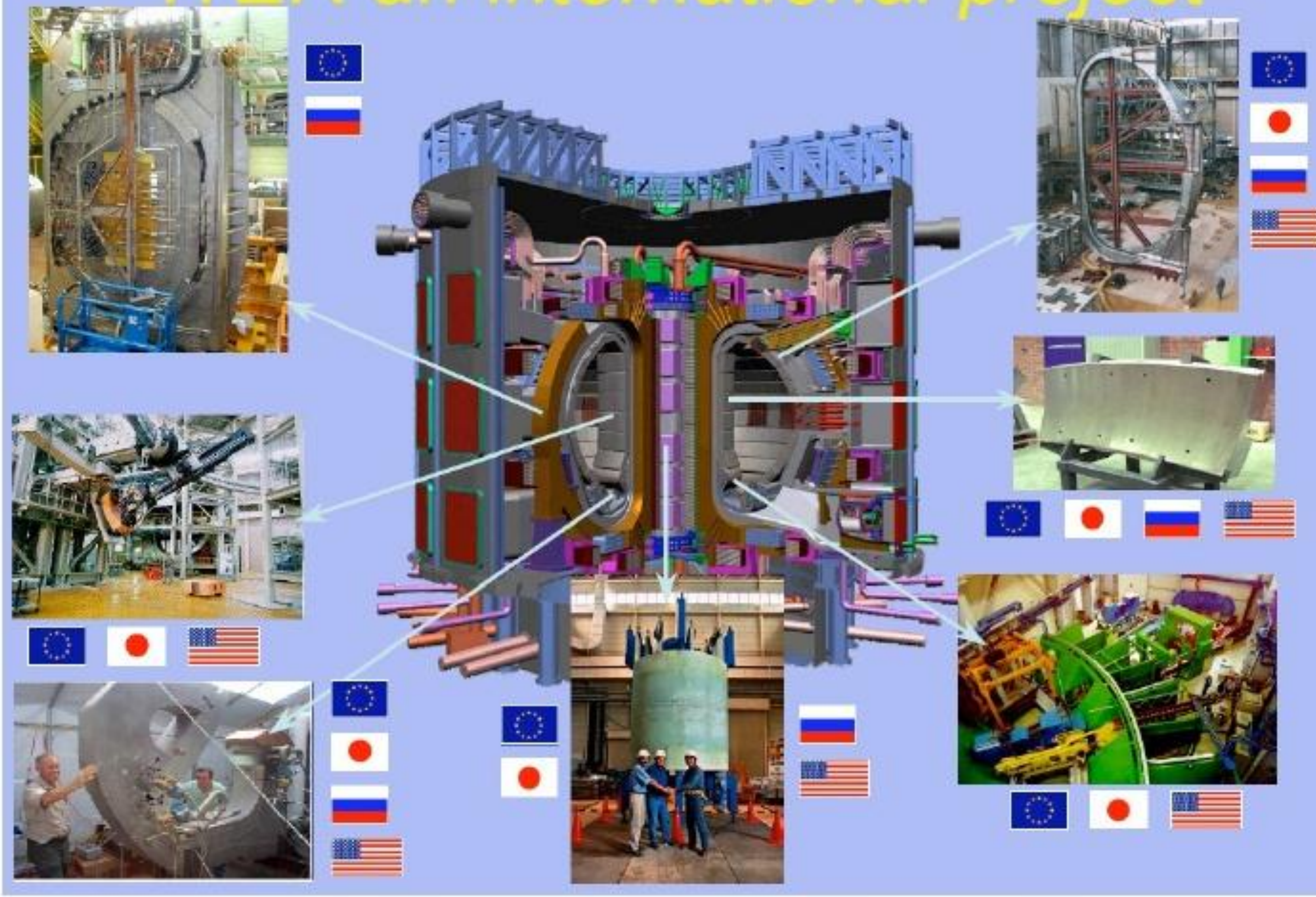
**Simulation:** *- Multi-physics, multi-scale modelling*
*- Co-developed numerical platforms*



# ITER & Development Pathway of Magnetic Fusion



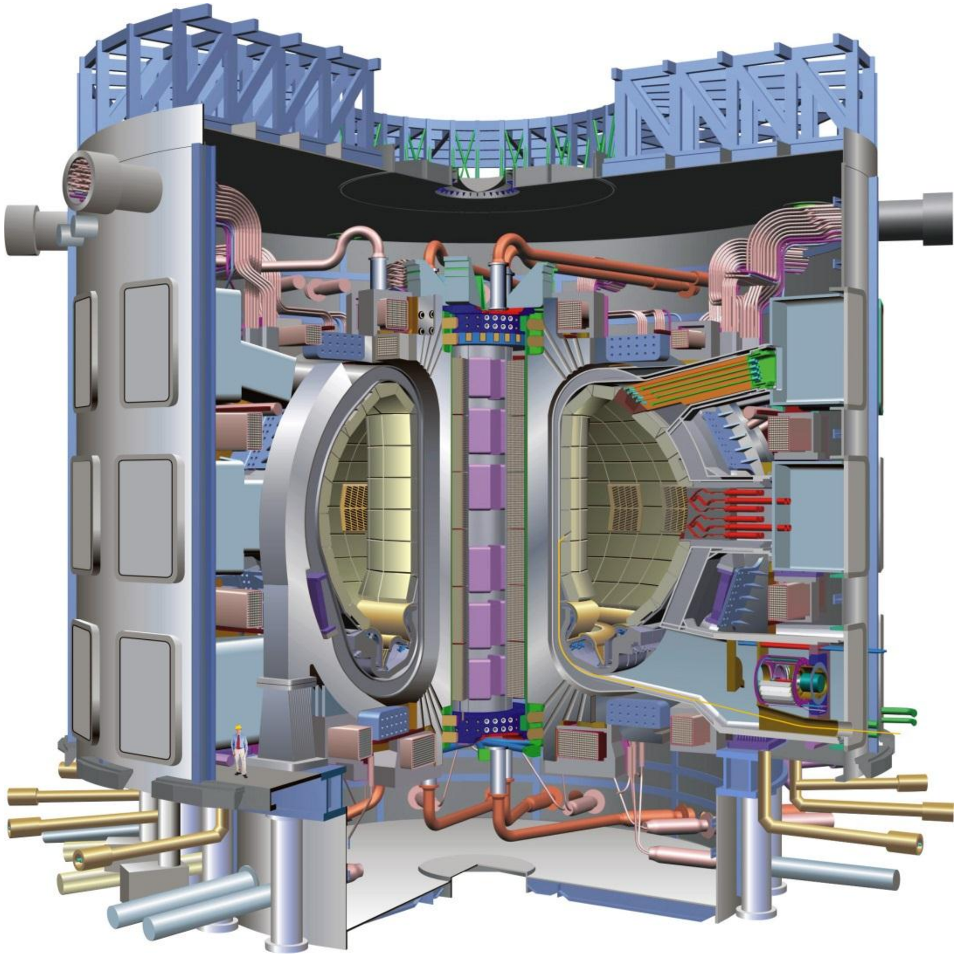
# ITER an international project



# ITER: A 20 Billion € project

Magnetic toroidal field 5.3 T
Injected power 50 MW
Output power: 500 MW
Power consumption 120 MW
I = 15 MA
Q= 10

Plasma height 7m



# Conclusions

- Most nations continue to follow their nuclear energy construction plans. **Nuclear energy is still perceived as a clean and economical source of energy**.
- All nations have realized the need for a new approach to safety and sustainability.
- Developping countries (China, India, etc.) are taking the lead
- Japan needs time to find the best way.
- Future nuclear fuel cycle is one of the most important issue (MIT report)
- ADS has a major window of opportunity. Several countries are interested (EU, China, India, etc.)
- Economics drive the future of nuclear energy and wastes management
- United States Nuclear Industry expects a rebound
- Pure and Applied Research has a fundamental role to innovate, support industry and give confidence in future designs

# Thank you

## Some useful web sites

**IEA ,NEA, IAEA, WANO, NEI, NASA,**

**US DOE**

**EU COMMISSION**

**ANL, CEA, Los Alamos,**

**BP, EXXON, SHELL**

**ITER**